Hybridization of
Crop Plants
Hybridization of Crop Plants

EDITORS:
WALTER R. FEHR AND HENRY H. HADLEY

Editorial Committee
R. A. FORSBERG  A. R. HALLAUER  A. W. HOVIN

Managing Editor
D. A. FUCCILLO

Coordinating Editor
MATTHIAS STELLY

American Society of Agronomy and Crop Science Society of America, Publishers
Madison, Wisconsin, USA
1980
Hybridization of crop plants.

Bibliography: 766 p. + xxvi
Includes index.

SB123.H9 631.5'23 80-12306
ISBN 0-89118-034-6

Revised in 1982.
FOREWORD

The publications of a scientific society are the chief tangible evidence of its vigor and vitality; they set a standard by which the society can be evaluated. The American Society of Agronomy and the Crop Science Society of America are pleased to have responded to the needs of our members and other agricultural workers and have shared in the development of this book dealing with hybridization of crop plants. Each chapter of this book was under the supervision of a member of an editorial committee jointly appointed by the American Society of Agronomy and the Crop Science Society of America.

This publication serves as a reference on the principles and procedures used to obtain hybrid seed of self and cross-pollinated crop plants. For many crops, descriptions of these procedures are passed orally from experienced to inexperienced persons and are not available in the literature. This book is not intended only as a text, but should be suitable as a reference even for persons inexperienced in plant breeding. It brings together the experience of plant breeders and other scientists in a form which can be used by persons unfamiliar with the crops and is intended for scientists, teachers, and students in plant science disciplines. It does not discuss in detail the breeding or genetics research for which the seed may be used.

The American Society of Agronomy and the Crop Science Society of America are pleased to bring you this special publication on a very important topic in agriculture. We express our deepest appreciation to Dr. Walter R. Fehr of Iowa State University and Dr. Henry H. Hadley of the University of Illinois, coeditors of the book and to the many authors.

ROY G. CREECH
Crop Science Society of America
Mississippi State, Mississippi

JOHN PESEK
American Society of Agronomy
Ames, Iowa

February 20, 1979
PREFACE

Hybridization and self-pollination are important aspects of research for the genetic improvement of crop plants. Hybridization is used to develop new genotypes, evaluate their performance, or exploit hybrid vigor. Self-pollination is used to evaluate genotypes and develop pure lines for cultivar development or genetic research.

This book was prepared to meet the need for written information on methods of hybridization and self-pollination of crop plants. A written description of methods used to obtain desired seed has not been available for many crop species. Successful procedures commonly are communicated verbally among scientists, and new techniques often are not considered important enough for publication in a journal. Lack of written information has hindered persons from learning successful methods without investing considerable effort in contacting scientists who have experience with a crop. Students also have not been able to obtain an overview of hybridization and self-pollination methods.

The book is intended to serve as both a text and a reference. The eight introductory chapters provide an overview of principles to be considered in hybridization and self-pollination, and should be of particular value to teachers and students. The remaining chapters provide detailed information on the procedures used for specific crops. Authors of the crop chapters followed identical subject headings to facilitate comparison of methods used in different species.

Preparation of a book of reasonable length and readability restricted the number of references that could be included by the authors. They were asked to include review articles and key references that would serve as a starting point for readers interested in a more exhaustive review of a subject. Personal communication with scientists provided considerable information, and each source of such information is documented.

The successful completion of this book is the result of the interest and participation of many scientists in the American Society of Agronomy and the Crop Science Society of America. Their first contribution was in the form of letters written early in 1976 to the societies in which they requested the preparation of a book that would bring together this important body of knowledge. The executive committees of the societies acknowledged this request, and appointed a feasibility committee to investigate the need, import, and contents of such a book. The committee, consisting of Walter R. Fehr, Chairman, Marvin K. Aycock, Jr., Jon L. Geadleman, Earl C. Gilmore, Darrell A. Miller, and G. Allan Taylor, recommended in December 1976 that the book be written. The Board of Directors of the societies approved the recommendation and agreed to cooperate in the venture. An editorial committee was appointed in January 1977. Over the next 2 years, numerous society members helped to identify qualified authors, provide information to those selected to prepare chapters, and review manuscripts. Their contribution is gratefully acknowledged.
It is with deepest gratitude that we acknowledge the contributions made by the authors. They were recommended to the editorial committee by their fellow scientists and are knowledgeable in a particular subject area or with a crop species. The quality of the book reflects their diligence in contacting colleagues for information, reviewing the literature, obtaining appropriate figures, and sharing their own experiences. We thank them for sharing their time and talents in service to others.

We acknowledge the contribution of the editorial committee: Robert Forsberg, Arnel Hallauer, and Arne Hovin, in preparing the outline for the book, selecting authors, and coordinating the preparation of individual chapters. The counsel of Domenic Fuccillo, managing editor, and the work of the societies' staff in the final editing of the book are gratefully acknowledged. We also thank the societies for financial support and encouragement.

Walter R. Fehr, Ames, Iowa
Henry H. Hadley, Urbana, Illinois
Coeditors
April 1979
CONTRIBUTORS

R. E. ALLAN, USDA-SEA, Department of Agronomy and Soils, Washington State University, Pullman, WA 99164
W. POWELL ANDERSON, Department of Agronomy, New Mexico State University, Las Cruces, NM 88003
A. K. AUCKLAND, International Crops Research Institute for the Semi-Arid Tropics, 1-11-256 Begumpet, Hyderabad 500016, A.P., India
D. K. BARNES, USDA-SEA, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55101
R. D. BARNETT, Department of Agronomy, University of Florida, Agricultural Research and Education Center, Quincy, FL 32351
E. C. BASHAW, USDA-SEA, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
BENJAMIN H. BEARD, USDA-SEA, Agronomy and Range Science, University of California, Davis, CA 95616
H. T. BLACKHURST, Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843
F. A. BLISS, Department of Horticulture, University of Wisconsin, Madison, WI 53706
D. A. BOND, Plant Breeding Institute, Cambridge, England
RAYMOND D. BRIGHAM, Texas Agricultural Experiment Station, Texas A&M University, Lubbock, TX 79401
C. M. BROWN, Department of Agronomy, University of Illinois, Urbana, IL 61801
BYRON L. BURSON, USDA-SEA, Grassland, Soil, and Water Research Laboratory, P.O. Box 748, Temple, TX 76501
GLENN W. BURTON, USDA-SEA, Georgia Coastal Plain Station, Tifton, GA 31794
W. RONNIE COFFMAN, Plant Breeding Department, International Rice Research Institute, Manila, Philippines
VERNE E. COMSTOCK, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55101
L. G. DALTON, Department of Sorghum Breeding, Pioneer Hi-Bred International, Inc., Plainview, TX 79072
WALTER DEDIO, Agriculture Canada, Research Station, Morden, Manitoba, Canada R0G 1J0
R. K. DOWNEY, Agriculture Canada, Research Station, Saskatoon, Saskatchewan, Canada S7N 0X2
W. ANSON ELLIOTT, Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN 55108
WALTER R. FEHR, Department of Agronomy, Iowa State University, Ames, IA 50011
R. A. FORSBERG, Department of Agronomy, University of Wisconsin, Madison, WI 53706
J. M. GREEN, International Crops Research Institute for the Semi-Arid Tropics, 1-11-256 Begumpet, Hyderabad 500016, A.P., India
EARL T. GRITTON, Department of Agronomy, University of Wisconsin, Madison, WI 53706
J. P. GUSTAFSON, Plant Sciences Department, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2
H. H. HADLEY, Department of Agronomy, University of Illinois, Urbana, IL 61801
A. R. HALLAUER, USDA-SEA, Department of Agronomy, Iowa State University, Ames, IA 50011
ALFRED HAUNOLD, USDA-SEA, Department of Crop Science, Oregon State University, Corvallis, OR 97331
R. M. HERRARA, Plant Breeding Department, International Rice Research Institute, Manila, Philippines
A. W. HOVIN, Agricultural Experiment Station, Montana State University, Bozeman, MT 59717
T. HYMOWITZ, Department of Agronomy, University of Illinois, Urbana, IL 61801
NORMAN I. JAMES, USDA-SEA, National Program Staff, Beltsville, MD 20705
A. JONES, USDA-SEA, U.S. Vegetable Laboratory, U.S. Department of Agriculture, Charleston, SC 29407
KAZUO KAWANO, Centro Internacional de Agricultura Tropical, Cali, Colombia
A. J. KLASSEN, Agriculture Canada, Research Station, Saskatoon, Saskatchewan, Canada S7N 0X2
P. F. KNOWLES, Department of Agronomy and Range Science, University of California, Davis, CA 95616
E. N. LARTER, Plant Science Department, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2
D. A. LAWES, Welsh Plant Breeding Station, Aberystwyth, Wales
JOSHUA A. LEE, USDA-SEA, Department of Crop Science, North Carolina State University, Raleigh, NC 27650
NELS R. LERSTEN, Department of Botany and Plant Pathology, Iowa State University, Ames, IA 50011
KOERT J. LESSMAN, Department of Agronomy, New Mexico State University, Las Cruces, NM 88003
D. J. MAJOR, Agriculture Canada, Research Station, Lethbridge, Alberta, Canada T1J 4B1
HAROLD G. MARSHALL, USDA-SEA, Department of Agronomy, Pennsylvania State University, University Park, PA 16802
D. F. MATZINGER, Department of Genetics, North Carolina State University, Raleigh, NC 27650
J. CREIGHTON MILLER, JR., Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843
D. D. MOREY, Department of Agronomy, University of Georgia, Coastal Plain Experiment Station, Tifton, GA 31794
F. J. MUEHLBAUER, USDA-SEA, Department of Agronomy and Soils, Washington State University, Pullman, WA 99164
A. J. NORDEN, Department of Agronomy, University of Florida, Gainesville, FL 32611
S. J. OPENSHAW, Department of Agronomy, University of Illinois, Urbana, IL 61801
JOHN F. OSBORNE, Soil Analysis Division, Department of Land Development, Phaholyothin Road, Bangkhen, Bangkok, Thailand
ROBERT L. PLAISTED, Department of Plant Breeding and Biometry, Cornell University, Ithaca, NY 14853
M. H. POULSEN, Royal Veterinary and Agricultural University, Taastrup, Denmark
ERIC D. PUTT, Agriculture Canada, Research Station, Morden, Manitoba, Canada R0G 1J0
CHARLES M. RICK, Department of Vegetable Crops, University of California, Davis, CA 95616
W. A. RUSSELL, Department of Agronomy, Iowa State University, Ames, IA 50011
K. F. SCHERTZ, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
D. SHARMA, International Crops Research Institute for the Semi-Arid Tropics, 1-11-256 Begumpet, Hyderabad 500016, A.P., India
D. P. SINGH, Jute Agricultural Research Institute, Barrackpore-743101, West Bengal, India
A. E. SLINKARD, Crop Development Centre, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 0X2
GARRY A. SMITH, USDA-SEA, Crops Research Laboratory, Colorado State University, Fort Collins, CO 80523
R. R. SMITH, USDA-SEA and Department of Agronomy, University of Wisconsin, Madison, WI 53706
R. E. STAFFORD, USDA-SEA, Texas A&M University Agricultural Research and Extension Center, Vernon, TX 73684
T. M. STARLING, Department of Agronomy, Virginia Polytechnic Institute and State University, Blacksburg, VA 24601
G. R. STRINGAM, Agriculture Canada, Research Station, Saskatoon, Saskatchewan, Canada S7N 0X2
CHARLES W. STUBER, Department of Genetics, North Carolina State University, Raleigh, NC 27650
NORMAN L. TAYLOR, Department of Agronomy, University of Kentucky, Lexington, KY 40546
C. E. TOWNSSEND, USDA-SEA, Crops Research Laboratory, Colorado State University, Fort Collins, CO 80523
L. J. G. VAN DER MAESEN, International Crops Research Institute for the Semi-Arid Tropics, 1-11-256 Begumpet, Hyderabad 500016, A.P., India
E. A. WERNMAN, Department of Crop Science, North Carolina State University, Raleigh, NC 27650
V. E. WILSON, USDA—SEA, Department of Agronomy and Soils, Washington State University, Pullman, WA 99164
HAROLD WRIGHT, Department of Quality Control, DeKalb AgResearch, Inc., DeKalb, IL 60115
DEMETRIOS M. YERMANOS, Department of Plant Sciences, University of California, Riverside, CA 92502
## CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Environmental Effects on Flowering</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D. J. MAJOR</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Response of Plants to Environment</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Phases of Plant Development</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>Day Length</td>
<td>3</td>
</tr>
<tr>
<td>IV</td>
<td>Temperature</td>
<td>6</td>
</tr>
<tr>
<td>V</td>
<td>Moisture</td>
<td>7</td>
</tr>
<tr>
<td>VI</td>
<td>Soil Fertility</td>
<td>8</td>
</tr>
<tr>
<td>VII</td>
<td>Techniques for Synchronizing Flowering Dates</td>
<td>8</td>
</tr>
<tr>
<td>VIII</td>
<td>Conditions for Successful Hybridization and Self-pollination</td>
<td>10</td>
</tr>
<tr>
<td>IX</td>
<td>Techniques for Rapid Seed Production</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Reproduction and Seed Development</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NELS R. LERSTEN</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>The Inflorescence</td>
<td>17</td>
</tr>
<tr>
<td>II</td>
<td>The Flower</td>
<td>20</td>
</tr>
<tr>
<td>III</td>
<td>Meiosis</td>
<td>30</td>
</tr>
<tr>
<td>IV</td>
<td>Pollination and Pollen-Stigma Interaction</td>
<td>34</td>
</tr>
<tr>
<td>V</td>
<td>Compatible Pollen Germination and Tube Growth</td>
<td>36</td>
</tr>
<tr>
<td>VI</td>
<td>Penetration of Embryo Sac and Fertilization</td>
<td>37</td>
</tr>
<tr>
<td>VII</td>
<td>Endosperm</td>
<td>38</td>
</tr>
<tr>
<td>VIII</td>
<td>The Embryo</td>
<td>39</td>
</tr>
<tr>
<td>IX</td>
<td>Apomixis and Male Sterility</td>
<td>41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Apomixis and Its Application in Crop Improvement</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E. C. BASHAW</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Mechanisms of Apomixis</td>
<td>46</td>
</tr>
<tr>
<td>II</td>
<td>Embryo Development in Apomicts</td>
<td>51</td>
</tr>
<tr>
<td>III</td>
<td>Indicators of Apomixis</td>
<td>52</td>
</tr>
<tr>
<td>IV</td>
<td>Techniques for Confirming Apomixis</td>
<td>54</td>
</tr>
<tr>
<td>V</td>
<td>Genetics of Apomixis</td>
<td>55</td>
</tr>
<tr>
<td>VI</td>
<td>Hybridization and Breeding of Apomixts</td>
<td>57</td>
</tr>
<tr>
<td>VII</td>
<td>Environmental Effects on Apomixis</td>
<td>61</td>
</tr>
<tr>
<td>VIII</td>
<td>Seed Production of Apomixts</td>
<td>61</td>
</tr>
</tbody>
</table>
Chapter 4  Sources, Maintenance, and Utilization of Parental Material ........................................ 65
R. A. FORSBERG AND R. R. SMITH

I. Sources of Germplasm ........................................ 66
II. Evaluation and Maintenance of Parental Material ........ 68
III. Utilization ........................................ 73

Chapter 5  Mating Designs, Field Nursery Layouts, and Breeding Records ................................. 83
CHARLES W. STUBER

I. Mating Designs ........................................ 83
II. Field Nursery Layouts .................................. 98
III. Breeding Records ..................................... 101

Chapter 6  Artificial Hybridization and Self-pollination .................................................. 105
WALTER R. FEHR

I. Selection of Parents ..................................... 105
II. Preparation of the Female Parent ....................... 106
III. Cross-pollination .................................... 118
IV. Self-pollination ...................................... 129
V. Seed Development .................................... 131

Chapter 7  Interspecific and Intergeneric Hybridization .................................................. 133
H. H. HADLEY AND S. J. OPENSHAW

I. Reproductive Isolation Barriers ....................... 135
II. Overcoming Reproductive Barriers .................. 142

Chapter 8  Commercial Hybrid Seed Production .................................................. 161
HAROLD WRIGHT

I. Types of Hybrids ...................................... 162
II. Obtaining Seed of Parent Lines ....................... 162
III. Field Selection ....................................... 164
IV. Optimizing Seed Set ................................ 166
V. Roguing ........................................... 169
VI. Artificial Emasculcation ................................ 169
VII. Harvest ........................................... 172
VIII. Seed Drying ....................................... 173
IX. Seed Conditioning .................................. 173
X. Quality Control ..................................... 174
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Common Bean</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td>I. Parental Material</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td>II. Plant Culture</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>III. Floral Characteristics</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td>IV. Artificial Hybridization and Self-pollination</td>
<td>277</td>
</tr>
<tr>
<td></td>
<td>V. Natural Hybridization</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>VI. Seed Development, Harvest, and Storage</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>VII. Techniques for Special Situations</td>
<td>282</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Cool-season Grasses</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>I. Parental Material</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>II. Plant Culture</td>
<td>286</td>
</tr>
<tr>
<td></td>
<td>III. Floral Characteristics</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>IV. Artificial Hybridization or Self-pollination</td>
<td>289</td>
</tr>
<tr>
<td></td>
<td>V. Natural Hybridization</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>VI. Seed Development, Harvest, and Storage</td>
<td>295</td>
</tr>
<tr>
<td></td>
<td>VII. Techniques for Special Situations</td>
<td>296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Corn</td>
<td>299</td>
</tr>
<tr>
<td></td>
<td>I. Parental Material</td>
<td>299</td>
</tr>
<tr>
<td></td>
<td>II. Plant Culture</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>III. Floral Characteristics</td>
<td>301</td>
</tr>
<tr>
<td></td>
<td>IV. Artificial Hybridization or Self-pollination</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>V. Natural Hybridization</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>VI. Seed Development, Harvest, and Storage</td>
<td>309</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Cotton</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>I. Parental Material</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>II. Plant Culture</td>
<td>315</td>
</tr>
<tr>
<td></td>
<td>III. Floral Characteristics</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td>IV. Artificial Hybridization or Self-pollination</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>V. Natural Hybridization</td>
<td>321</td>
</tr>
<tr>
<td></td>
<td>VI. Seed Development, Harvest, and Storage</td>
<td>322</td>
</tr>
<tr>
<td></td>
<td>VII. Techniques for Special Situations</td>
<td>323</td>
</tr>
</tbody>
</table>
Chapter 25  Forage Legumes ........................................ 367
C. E. TOWNSEND

I. Parental Material ........................................ 367
II. Plant Culture ........................................ 370
III. Floral Characteristics ................................. 372
IV. Artificial Hybridization or Self-pollination .... 373
V. Natural Hybridization ................................ 375
VI. Seed Development, Harvest, and Storage ....... 376

Chapter 26  Guar .............................................. 381
R. E. STAFFORD and T. HYMOWITZ

I. Parental Material ........................................ 381
II. Plant Culture ........................................ 383
III. Floral Characteristics ................................. 384
IV. Artificial Hybridization or Self-pollination .... 387
V. Natural Hybridization ................................ 390
VI. Seed Development, Harvest, and Storage ....... 391

Chapter 27  Hop .............................................. 393
ALFRED HAUNOLD

I. Parental Material ........................................ 393
II. Plant Culture ........................................ 394
III. Floral Characteristics ................................. 398
IV. Artificial Hybridization .............................. 400
V. Natural Hybridization ................................ 404
VI. Seed Development, Harvest, and Storage ....... 404
VII. Techniques for Special Situations ................. 405

Chapter 28  Jute ............................................. 407
D. P. SINGH

I. Parental Material ........................................ 407
II. Plant Culture ........................................ 408
III. Floral Characteristics ................................. 409
IV. Artificial Hybridization or Self-pollination .... 410
V. Natural Hybridization ................................ 413
VI. Seed Development, Harvest, and Storage ....... 414
VII. Techniques for Special Situations ................. 415
<table>
<thead>
<tr>
<th>Chapter 29</th>
<th>Lentil .................................................</th>
<th>417</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Parental Material ..................................</td>
<td>417</td>
</tr>
<tr>
<td>II.</td>
<td>Plant Culture .......................................</td>
<td>418</td>
</tr>
<tr>
<td>III.</td>
<td>Floral Characteristics ............................</td>
<td>421</td>
</tr>
<tr>
<td>IV.</td>
<td>Artificial Hybridization or Self-pollination ...</td>
<td>422</td>
</tr>
<tr>
<td>V.</td>
<td>Natural Hybridization .............................</td>
<td>425</td>
</tr>
<tr>
<td>VI.</td>
<td>Seed Development, Harvest, and Storage ..........</td>
<td>425</td>
</tr>
<tr>
<td>VII.</td>
<td>Techniques for Special Situations ...............</td>
<td>425</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 30</th>
<th>Oat ..................................................</th>
<th>427</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Parental Material ..................................</td>
<td>427</td>
</tr>
<tr>
<td>II.</td>
<td>Plant Culture ......................................</td>
<td>428</td>
</tr>
<tr>
<td>III.</td>
<td>Floral Characteristics ...........................</td>
<td>429</td>
</tr>
<tr>
<td>IV.</td>
<td>Artificial Hybridization or Self-pollination ...</td>
<td>432</td>
</tr>
<tr>
<td>V.</td>
<td>Natural Hybridization ................................</td>
<td>440</td>
</tr>
<tr>
<td>VI.</td>
<td>Seed Development, Harvest, and Storage ..........</td>
<td>440</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 31</th>
<th>Peanut ................................................</th>
<th>443</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Parental Material ..................................</td>
<td>443</td>
</tr>
<tr>
<td>II.</td>
<td>Plant Culture ......................................</td>
<td>444</td>
</tr>
<tr>
<td>III.</td>
<td>Floral Characteristics ...........................</td>
<td>446</td>
</tr>
<tr>
<td>IV.</td>
<td>Artificial Hybridization or Self-pollination ...</td>
<td>448</td>
</tr>
<tr>
<td>V.</td>
<td>Natural Hybridization ................................</td>
<td>453</td>
</tr>
<tr>
<td>VI.</td>
<td>Seed Development, Harvest, and Storage ..........</td>
<td>453</td>
</tr>
<tr>
<td>VII.</td>
<td>Techniques for Special Situations ...............</td>
<td>453</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 32</th>
<th>Pearl Millet .........................................</th>
<th>457</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Parental Material ..................................</td>
<td>457</td>
</tr>
<tr>
<td>II.</td>
<td>Plant Culture ......................................</td>
<td>458</td>
</tr>
<tr>
<td>III.</td>
<td>Floral Characteristics ...........................</td>
<td>459</td>
</tr>
<tr>
<td>IV.</td>
<td>Artificial Hybridization or Self-pollination ...</td>
<td>460</td>
</tr>
<tr>
<td>V.</td>
<td>Natural Hybridization ................................</td>
<td>465</td>
</tr>
<tr>
<td>VI.</td>
<td>Seed Development, Harvest, and Storage ..........</td>
<td>467</td>
</tr>
<tr>
<td>VII.</td>
<td>Techniques for Special Situations ...............</td>
<td>467</td>
</tr>
</tbody>
</table>
Chapter 33  Pigeonpea .............................................. 471
            D. SHARMA AND J. M. GREEN

            I. Parental Material ........................................ 471
            II. Plant Culture ........................................... 472
            III. Floral Characteristics ................................ 474
            IV. Artificial Hybridization or Self-pollination ........... 475
            V. Natural Hybridization ................................... 478
            VI. Seed Development, Harvest, and Storage ............... 479

Chapter 34  Potato .................................................. 483
            ROBERT L. PLAIISTED

            I. Parental Material ........................................ 483
            II. Plant Culture ........................................... 485
            III. Floral Characteristics ................................ 486
            IV. Artificial Hybridization or Self-pollination ........... 488
            V. Natural Hybridization ................................... 491
            VI. Seed Development, Harvest, and Storage ............... 491
            VII. Techniques for Special Situations .................... 492

Chapter 35  Rapeseed and Mustard ................................. 495
            R. K. DOWNEY, A. J. KLASSEN, AND G. R. STRINGAM

            I. Parental Material ........................................ 496
            II. Plant Culture ........................................... 496
            III. Floral Characteristics ................................ 498
            IV. Artificial Hybridization or Self-pollination ........... 500
            V. Natural Hybridization ................................... 502
            VI. Seed Development, Harvest, and Storage ............... 504
            VII. Techniques for Special Situations .................... 505

Chapter 36  Rice .................................................... 511
            W. RONNIE COFFMAN AND R. M. HERRERA

            I. Parental Material ........................................ 511
            II. Plant Culture ........................................... 512
            III. Floral Characteristics ................................ 513
            IV. Artificial Hybridization or Self-pollination ........... 513
            V. Natural Hybridization ................................... 520
            VI. Seed Development, Harvest, and Storage ............... 520
            VII. Techniques for Special Situations .................... 521
Chapter 37  Rye ........................................ 523
D. D. MOREY AND R. D. BARNETT
   I. Parental Material .................................. 523
   II. Plant Culture .................................... 524
   III. Floral Characteristics .......................... 525
   IV. Artificial Hybridization or Self-pollination .... 528
   V. Natural Hybridization ............................ 532
   VI. Seed Development, Harvest, and Storage ........ 532
   VII. Techniques for Special Situations ............. 532

Chapter 38  Safflower .................................. 535
P. F. KNOWLES
   I. Parental Material .................................. 535
   II. Plant Culture .................................... 537
   III. Floral Characteristics .......................... 539
   IV. Artificial Hybridization or Self-pollination .... 543
   V. Natural Hybridization ............................ 546
   VI. Seed Development, Harvest, and Storage ........ 546
   VII. Techniques for Special Situations ............. 547

Chapter 39  Sesame ..................................... 549
DEMITRIOS M. YERMANOS
   I. Parental Material .................................. 549
   II. Plant Culture .................................... 550
   III. Floral Characteristics .......................... 552
   IV. Artificial Hybridization or Self-pollination .... 555
   V. Natural Hybridization ............................ 561
   VI. Seed Development, Harvest, and Storage ........ 561

Chapter 40  Sisal and Other Long Fiber Agaves ............ 565
JOHN F. OSBORNE AND D. P. SINGH
   I. Parental Material .................................. 566
   II. Plant Culture .................................... 568
   III. Floral Characteristics .......................... 570
   IV. Artificial Hybridization or Self-pollination .... 573
   V. Natural Hybridization ............................ 574
   VI. Seed Development, Harvest, and Storage ........ 574
Chapter 41  Sorghum  ........................................... 577

K. F. SCHERTZ AND L. G. DALTON

   I. Parent Material ........................................... 577
   II. Plant Culture ........................................... 578
   III. Floral Characteristics ................................. 579
   IV. Artificial Hybridization or Self-pollination ........ 582
   V. Natural Hybridization ................................... 586
   VI. Seed Development, Harvest, and Storage ............ 587

Chapter 42  Soybean  ........................................... 589

WALTER R. FEHR

   I. Parental Material ........................................... 589
   II. Plant Culture ........................................... 590
   III. Floral Characteristics ................................. 592
   IV. Artificial Hybridization or Self-pollination ........ 594
   V. Natural Hybridization ................................... 597
   VI. Seed Development, Harvest, and Storage ............ 597

Chapter 43  Sugarbeet  ......................................... 601

GARRY A. SMITH

   I. Parental Material ........................................... 601
   II. Plant Culture ........................................... 603
   III. Floral Characteristics ................................. 605
   IV. Artificial Hybridization or Self-pollination ........ 607
   V. Natural Hybridization ................................... 610
   VI. Seed Development, Harvest, and Storage ............ 613
   VII. Techniques for Special Situations ................. 613

Chapter 44  Sugarcane  ......................................... 617

NORMAN I. JAMES

   I. Parental Material ........................................... 617
   II. Plant Culture ........................................... 618
   III. Floral Characteristics ................................. 619
   IV. Artificial Hybridization or Self-pollination ........ 623
   V. Natural Hybridization ................................... 627
   VI. Seed Development, Harvest, and Storage ............ 627